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PRELIMINARY REPORT ON THE FLAT-TOP LIFT CURVE AS A FACTOR IN CONTROL AT LOW SPEED

By Montgomery Knight and Millard J. Bamber
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PRELIMINARY REPORT ON THE FLAT TOP LIFT CURVE AS A FACTOR IN CONTROL AT LOW SPEED.

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Summary

This report, which is the first of a general airplane safety program, is concerned with the importance of the flat-top lift curve as a factor contributing to safety and control at low speed. An analysis of existing airfoil data indicated definite relations between the shape of the lift curve and certain section dimensions. A sectiom (NACA 84), designed according to these empirical relations, was tested and found to have the desired flat-top lift curve combined, however, with low aerodynamic efficiency and high moment coefficients. The shape of the lift curve at maximum lift appears to be of sufficient importance to justify additional investigation with the view of developing a section having satisfactory efficiency and moment characteristics.

Introduction

The most critical feature of airplane flight to-day is the making of a safe and comfortable contact with ground or water on landing. The skill required in landing under all possible

conditions must be reduced if safety in civil aviation is to be assured. Surprisingly little work has been done to date on this vital matter.

The chief factor to be considered in the problem is the nature of the air reactions upon the airplane as it assumes a landing attitude on approaching the ground. The most important aerodynamic item is the manner in which the lift varies with changes in angle of attack of the wing system at low speeds or large angles of attack. Safety demands that there be no abrupt changes in lift at these angles. In other words, it is highly desirable that the lift curve should have a flat top instead of the relatively sharp peak generally characteristic of airfoils in use at present.

This requirement calls for a study of the aerodynamics of airfoils at large angles of attack. During the past two years such a study has been made at the Langley Memorial Aeronautical Laboratory as a part of a general airplane safety program undertaken by the staff of the atmospheric wind tunnel. The latest development is the N.A.C.A. 84 airfoil profile, and the major portion of this report deals with the results of force tests on an airfoil model having this profile.

Preliminary Airfoil Tests

The shape of the lift curve in the vicinity of its maximum depends chiefly on the manner in which the flow separation or

"burble" takes place over the upper surface of the airfoil. The design of an airfoil having a flat-top lift curve requires a knowledge of the airfoil shape factors that affect this flow separation. To investigate these factors, preliminary force tests were made on several airfoils having extreme profiles, and from these tests the following tentative rules for obtaining profiles with flat-top lift curves were derived:

1. The shape of the upper surface is vital, whereas that of the lower is unimportant.
2. The maximum ordinate should be well back, in the vicinity of forty per cent of the chord from the leading edge.
3. The nose should be low and have a fairly small radius of curvature.
4. The upper surface should be a simple mathematical curve, i.e., the change in radius of curvature should be continuous along the surface.
5. The thickness should be medium, 12 to 16 per cent of the chord.

N.A.C.A. 84 Airfoil Tests and Results

The N.A.C.A. 84 airfoil profile, which was designed in accordance with the above rules, is shown in Figure 1, and its ordinates are given in Table I. This profile is of the Joukowsky type (Reference 1), and has a medium thickness $(\delta/l = .05)$

and high mean camber $(f/l = .15)$, with the Joukowsky concave lower surface camber replaced by a straight line.

Force tests were made on a 5 in. by 30 in. rectangular airfoil model of laminated mahogany. The model was mounted in the tunnel (Reference 2), on the wire balance, and lift, drag, and pitching moments were measured through a range from -8° to $+35^\circ$ angle of attack. The dynamic pressure q, was held constant at 4.04 lb. per sq.ft. (19.8 kg/m²) which represented an average air speed of about 40 M.P.H. (17.9 m.p.s.). The average Reynolds Number was 148,000, with the wing chord as the characteristic length.

The test results were corrected for the effects of the supporting wires. Also, the effect of the tunnel walls on the air flow over the model was accounted for by considering the test results as applying to a wing of aspect ratio 6.85 in free air. This value for the 30 in. wing in the 60 in. circular closed-throat tunnel was obtained by means of the Prandtl correction formula.

The ordinates of the model were accurate to within $\pm.003$ in. In general, the test results may be relied on to within ± 2 per cent.

The results are presented in Table II and also in Figures 2, 3, 4, and 5. Absolute lift and drag coefficients C_L and C_D, and L/D are plotted against angle of attack α, in Figure 2. The polar curve C_D, plotted against C_L, is given

in Figure 3.

Figure 4 is a diagram of the resultant force at various angles of attack presented in vector form. The lines A and B show the effect of locating the center of gravity below or above the wing, respectively.

In Figure 5 is shown the center of pressure travel in per cent of chord from the leading edge plotted against angle of attack for these two c.g. positions and also for the wing chord line.

Discussion

Figure 2 shows that from $9\frac{1}{2}^{\circ}$ to 19° angle of attack, a range of $9\frac{1}{2}^{\circ}$, the mean variation in lift is about one per cent. An airplane equipped with this type of wing would have much less critical landing characteristics than if it had a wing with a peaked lift curve. This is due to the fact that once the flat portion of the curve has been reached, pulling back the control stick would cause neither a sudden rise nor an abrupt drop of the airplane.

A large proportion of airplane crashes to-day may be accounted for by the sudden uncontrolled dive following a stall when close to the ground. This dive is due to the relatively rapid rearward motion of the center of pressure as the angle of maximum lift is exceeded whereby a strong nosing down tendency is produced. At the same time, due to the low speed, the ele-

vator effect is too small to hold the nose up, and the airplane consequently crashes nose down. This characteristic, in general, is much stronger in staggered biplanes and low-wing monoplanes than in the high-wing monoplane. Figures 4 and 5 show graphically that, for the N.A.C.A. 84 airfoil from 4° to 35°, the center of pressure is very nearly stationary along a line (A) at a distance of 0.4 of the chord below the chord line. A monoplane with center of gravity on this line would (except for the tail surfaces) be practically in neutral equilibrium over a large range of angles and would have no tendency to nose down. Incidentally, these two figures also show the relatively large rearward center of pressure travel that would obtain in a monoplane with the center of gravity on line (B).

Still another desirable feature of this type of airfoil is its small spinning tendency. Autorotation calculations indicate an approximate range of "rotary instability" of only 4° as compared to that of about 8° or more for several commonly used airfoils. The method of calculation is explained in Reference 3.

At zero lift the value of the absolute pitching moment coefficient C_M about the quarter-chord point is 0.135. This is larger than is obtained on most of the commonly used airfoils. Moreover, the aerodynamic efficiency is not high, being about the same as that for the well-known Göttingen 387. The investigation is to be continued in order to improve these two undesirable conditions without, however, sacrificing the flat-top

lift curve and the good low speed stability characteristics.

In considering the above discussion, the low scale (R.N. = 148,000) of the tests should be kept in mind. However, it is believed that the scale effect on the N.A.C.A. 84 airfoil at maximum lift is small. This statement is based on the results obtained on airfoils of approximately the same thickness which have been tested at this laboratory in the variable density wind tunnel.

Conclusions

A study of the data now available leads to the following conclusions:

1. The flat-top lift curve should make landing a safer and less difficult operation.

2. The flat-top lift curve when combined with a small center of pressure movement at large angles of attack should reduce the tendency to dive after a stall.

3. An airfoil having a flat-top lift curve also has a reduced tendency to spin and would therefore be less apt to fall off on one wing after a stall at low altitude.

4. Owing to the high moment coefficient and low aerodynamic efficiency the N.A.C.A. 84 section is not considered satisfactory, but satisfactory sections can probably be developed and further work along this line is being planned.

B i b l i o g r a p h y

Reference 1. Trefftz, E. : "Graphic Construction of Joukowsky Wings." N.A.C.A. Technical Memorandum No. 336. (1925)

Reference 2. Reid, Elliott G. : "Standardization Tests of N.A.C.A. No. 1 Wind Tunnel." N.A.C.A. Technical Report No. 195. (1924)

Reference 3. Knight, Montgomery: "Wind Tunnel Tests on Autorotation and the Flat Spin." N.A.C.A. Technical Report No. 273. (1927)

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 26, 1928.

Table I.

N.A.C.A. 84 Airfoil Ordinates

Station % Chord from L.E.	Upper Surface % Chord	Lower Surface % Chord
0	2.50	2.50
0.5	3.90	1.55
1.25	4.85	0.95
2.50	6.05	0.41
5.00	7.78	0.10
7.50	9.03	0.02
8.50	--	0
10.00	10.00	0
15.00	11.50	0
20.00	12.71	0
25.00	13.51	0
30.00	14.00	0
35.00	14.18	0
40.00	14.11	0
50.00	13.50	0
60.00	12.31	0
70.00	10.33	0
80.00	7.71	0
90.00	4.59	0
95.00	2.41	0
100.00	0.30	0

Table II

Force Test - Atmospheric Wind Tunnel.
Model - N.A.C.A. 84 wing, 5 in. by 30 in. rectangular.
Effective Aspect Ratio = 6.85.
Dynamic Pressure (q) = 19.8 kg/m².
Reynolds Number = 148,000.

Deg.	C_L abs.	C_D abs.	L/D	C.P. in % chord from L.E. (See Fig. 4)		
				Chord	A	B
-8	-.054	.070	-0.77	--	--	--
-4	+.224	.026	8.45	82.0	74.4	89.5
0	.538	.035	15.50	48.0	45.4	50.3
4	.851	.057	15.10	39.7	39.9	39.3
6	.947	.072	13.20	38.2	38.9	36.9
8	1.040	.089	11.70	36.9	39.0	34.4
9	1.066	.096	11.10	--	--	--
10	1.087	.106	10.20	36.0	39.0	32.7
11	1.095	.115	9.52	--	--	--
12	1.098	.124	8.64	35.2	39.0	31.2
14	1.102	.150	7.33	34.3	38.7	29.7
16	1.106	.180	6.15	34.1	38.8	29.2
18	1.095	.222	5.17	34.4	39.3	29.2
20	1.060	.304	3.48	36.5	39.0	33.4
21	.932	.354	2.63	38.3	39.0	37.8
22	.866	.380	2.28	39.5	38.4	40.4
25	.854	.453	1.91	40.9	38.4	41.9
30	.891	.566	1.57	41.1	39.1	42.9
35	.885	.680	1.30	40.5	38.9	42.2

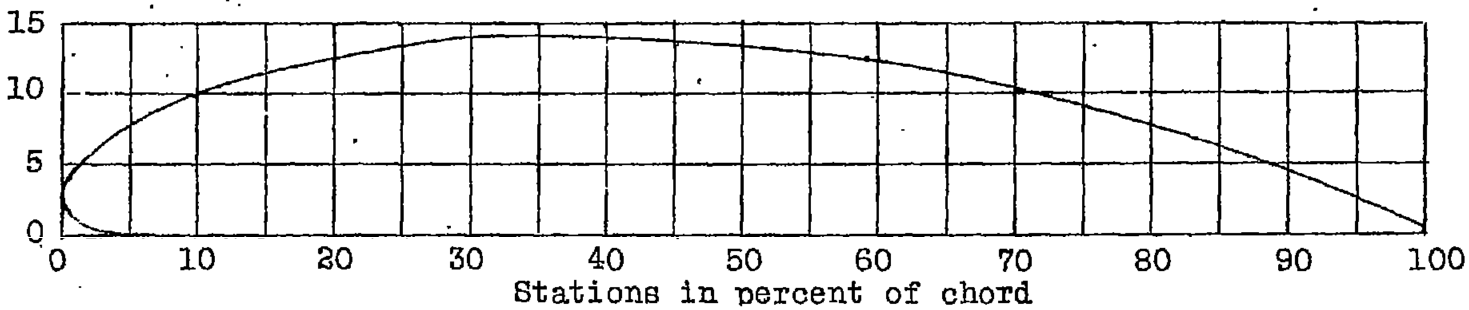

Fig.1 N.A.C.A. 84 Airfoil. Ordinates given in Table I.

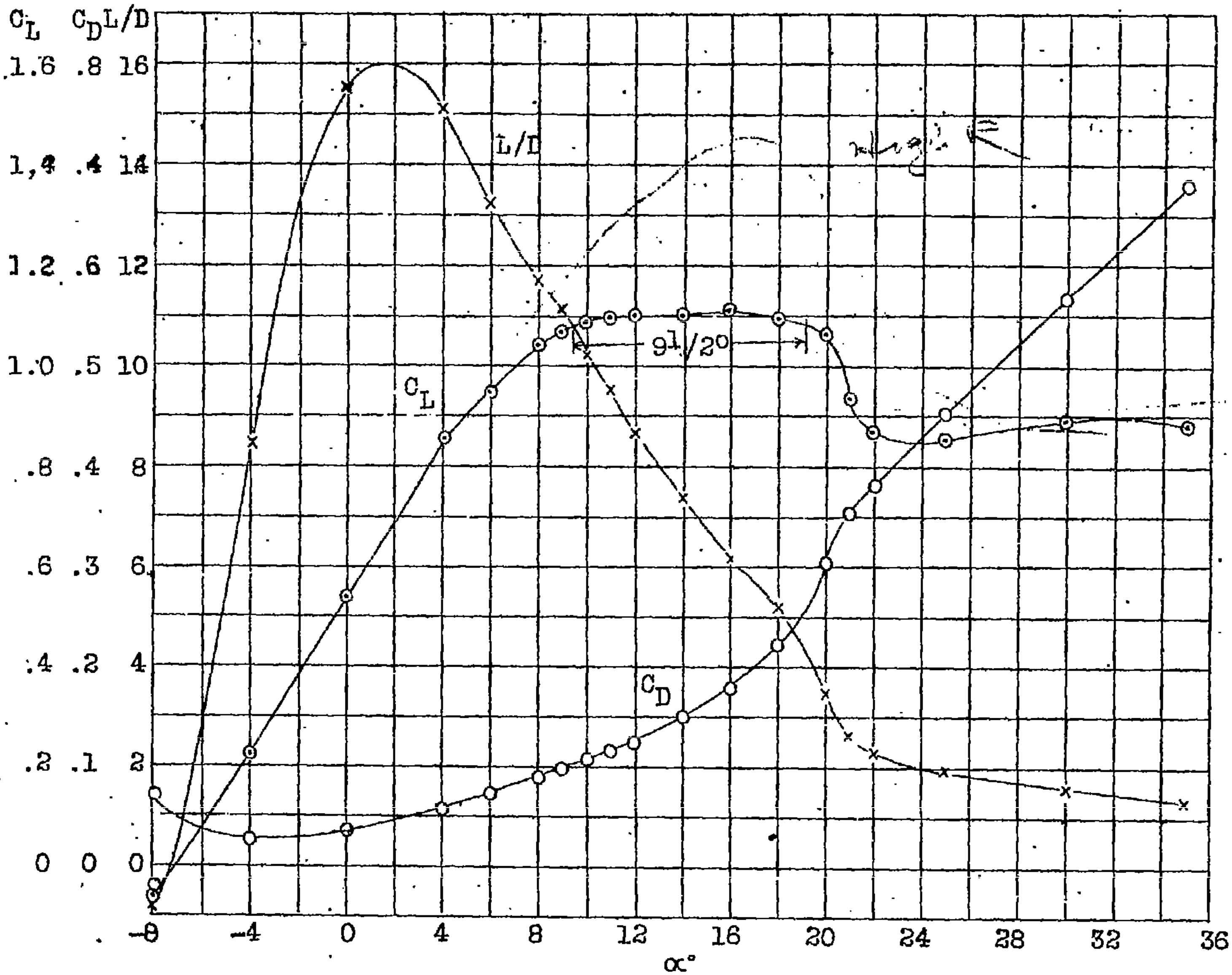

Fig.2 Lift, drag and L/D vs angle of attack. Aspect ratio = 6.85

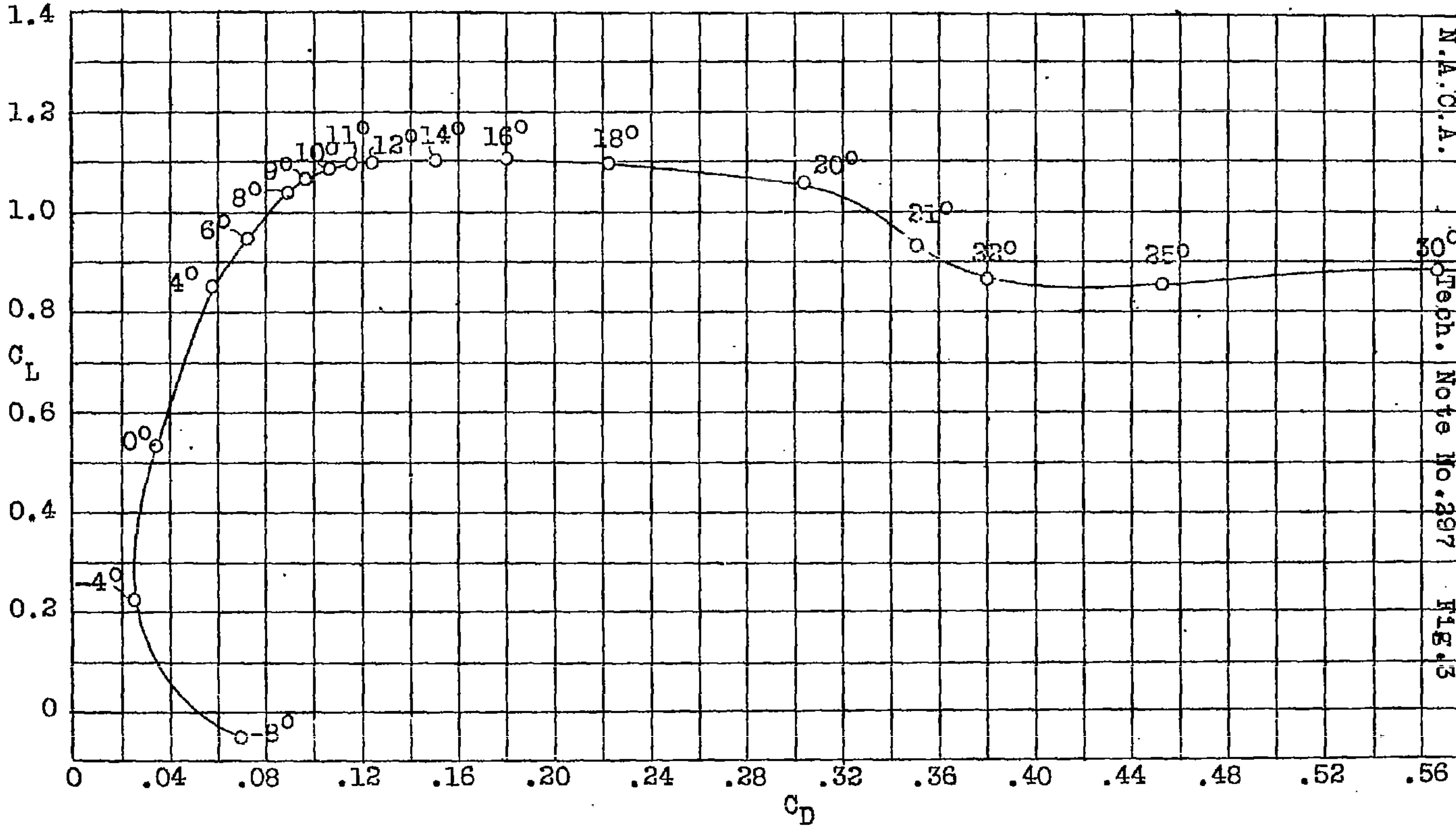

Fig.3 Polar curve for N.A.C.A. 84 airfoil. Aspect ratio = 6.85.

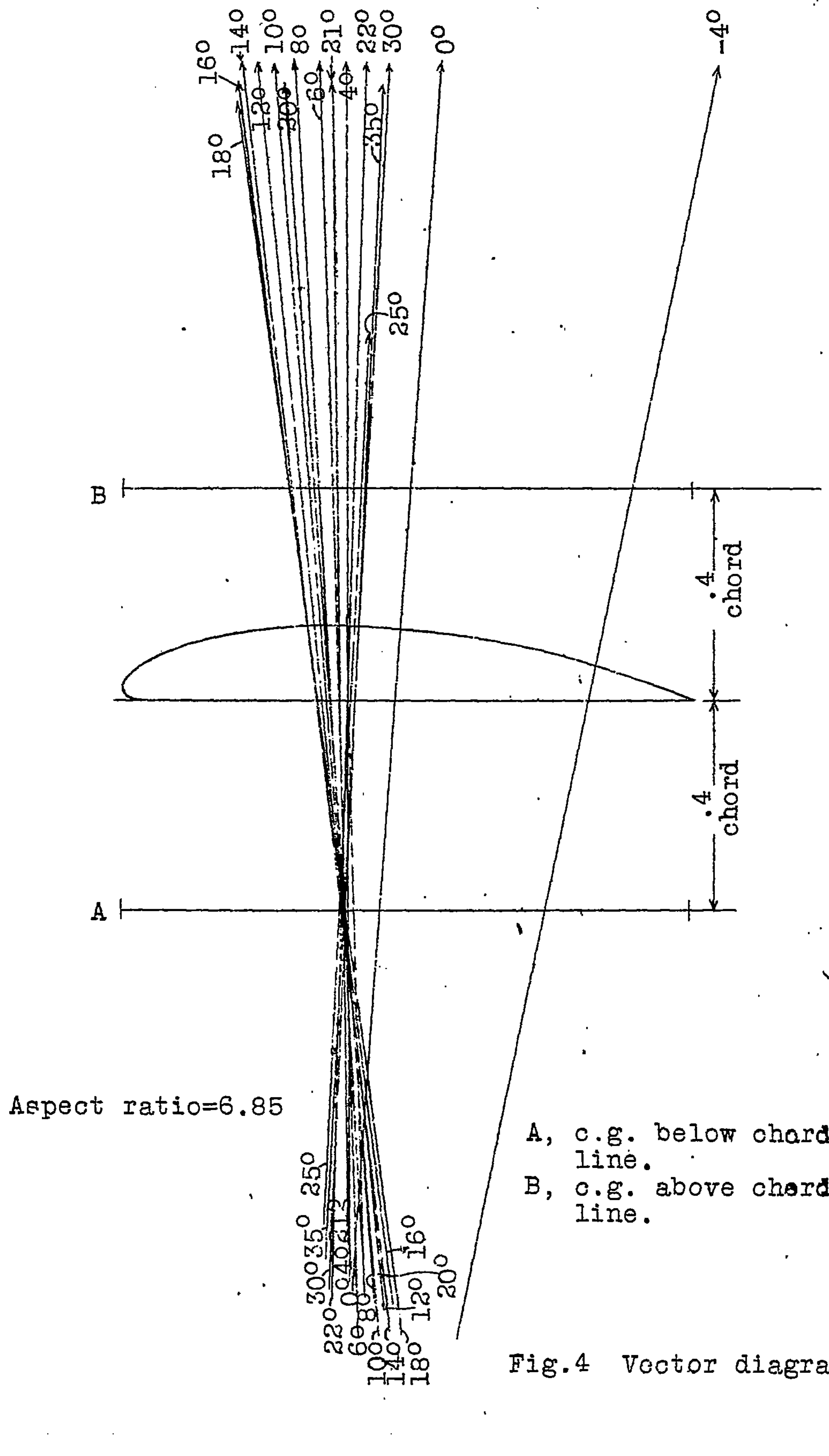

Fig.4 Vector diagram.

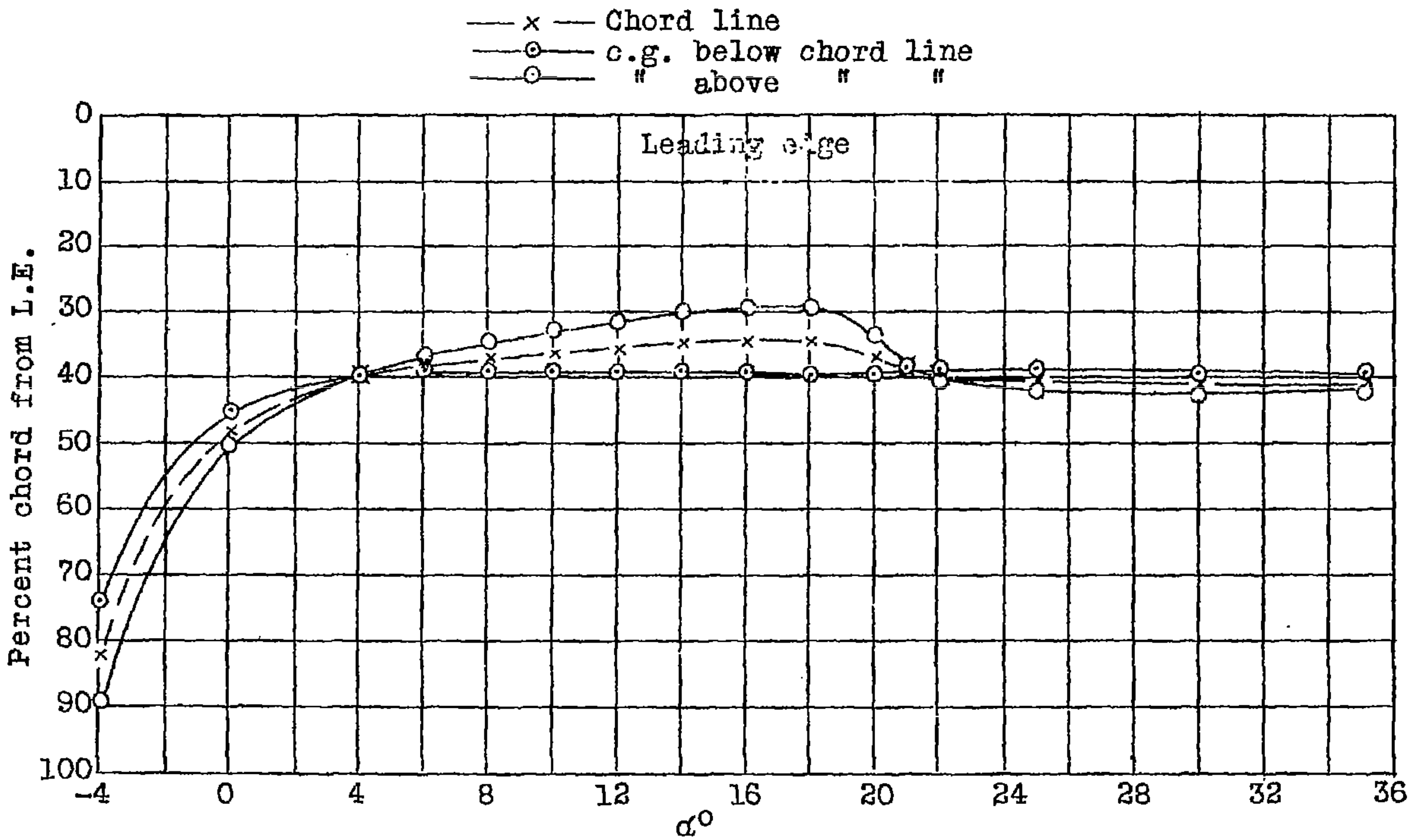

Fig.5 Center of pressure travel vs angle of attack. Aspect ratio = 6.85